

Bursting dwarf galaxies from the far-UV and deep surveys

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ABSTRACT

The far-ultraviolet (UV) counts and the deep optical spectroscopic surveys have revealed an unexpected number of very blue galaxies (vBG). Using constraints from the UV and optical, we apply the galaxy evolution model PEGASE (Fioc & Rocca-Volmerange 1997, hereafter FRV) to describe this population with a cycling star formation. When added to normally evolving galaxy populations, vBG are able to reproduce UV number counts and color distributions as well as deep optical redshift distributions fairly well. Good agreement is also obtained with optical counts (including the Hubble Deep Field). The number of vBG is only a small fraction of the number of normal galaxies, even at faintest magnitudes. In our modelling, the latter explain the bulk of the excess of faint blue galaxies in an open Universe. The problem of the blue excess remains in a flat Universe without cosmological constant.

Key words: galaxies: evolution – galaxies: starburst – galaxies: luminosity function, mass function – ultraviolet: galaxies – cosmology: miscellaneous

1 INTRODUCTION

The apparent excess of the number of galaxies at faint magnitudes in the blue relative to predictions of non-evolving models, even in the most favourable case of an open Universe, is a longstanding problem of cosmology. Various scenarios have been proposed to solve this problem in a flat Universe, as a strong number density evolution of galaxies via merging (Rocca-Volmerange & Guiderdoni 1990; Broadhurst, Ellis & Glazebrook 1992) or with a cosmological constant (Fukugita et al. 1990). In the framework of more conservative pure luminosity evolution models in an open Universe, two solutions were advocated. Either these blue galaxies are intensively star forming galaxies at high redshift, or counts are dominated by a population of intrinsically faint blue nearby galaxies. Looking for the optimal luminosity functions (LF) fitting most observational constraints, Gronwall & Koo (1995) have introduced in particular *non-evolving populations* of faint *very* blue galaxies (see also Pozzetti, Bruzual & Zamorani (1996)), contributing significantly to faint counts. Such blue colors require however that *individual* galaxies have recently been bursting and are thus rapidly evolving. With a modelling of the spectral evolution of these galaxies taking also in consideration post-burst phases, Bouwens & Silk (1996) concluded that the LF adopted by Gronwall & Koo (1995) leads to a strong excess

of nearby galaxies in the redshift distribution and that vBG may thus not be the main explanation of the blue excess.

On the basis of considerable observational progress in collecting deep survey data, it is timely to address the question of the nature of the blue excess anew, with the help of our new model PEGASE (FRV). In this paper, we propose a star formation scenario and a LF respecting the observational constraints on vBG. Far-UV and optical counts are well matched with the classical Hubble Sequence population and that bursting population extension. The importance of vBG relative to normal galaxies and the physical origin of bursts are finally discussed in the conclusion.

2 OBSERVATIONAL EVIDENCES OF VERY BLUE GALAXIES

In contrast with the so-called ‘normal’ galaxies of the Hubble Sequence, supposed to form at high redshift with definite star formation timescales, bursting galaxies are rapidly evolving without clear timescales. Specifically, in the red post-burst phases, they might be undistinguishable from normal slowly evolving galaxies. The bluest phases during the burst should, however, allow to recognize them and to constrain their evolution and their number.

The existence of galaxies much bluer than normal and classified as starbursts has been recently noticed at optical wavelengths by Heyl et al. (1997). At fainter magnitudes ($B = 22.5 - 24$), Cowie et al. (1996) deep survey has revealed two populations of blue ($B - I < 1.6$) galaxies (Figs. 1 and

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3). Normal star forming galaxies, as predicted by standard models, are observed at high redshift ($z > 0.7$) but another, clearly distinct population of blue galaxies is identified at $0 < z < 0.3$, among which some of them are very blue.

The best constraint on the weight of these vBG comes from the far-UV (2000 Å) bright counts observed with the balloon experiment FOCA2000 (Armand & Milliard 1994). By using a standard LF, the authors obtain a strong deficit of predicted galaxies in UV counts all along the magnitude range ($UV = 14 - 18$) and argue in favour of a LF biased towards later-type galaxies. With the star formation scenarios and the LF of Marzke et al. (1994) fitting optical and near-infrared bright counts (FRV), we confirm that this UV deficit reaches a factor 2 (Fig. 2). Moreover, the $UV - B$ color distributions show a clear lack of blue galaxies and notably of those with $UV - B < -1.5$ (Fig. 2). A 10 Gyr old galaxy which formed stars at a constant rate, would however only have $UV - B \sim -1.2$. Although a low metallicity may lead to bluer colors, it will still be too red and a population of bursting galaxies is clearly needed to explain UV counts and the Cowie et al. (1996) data.

3 MODELING VERY BLUE GALAXIES

3.1 Star formation scenario

Very blue colors are possible only in very young galaxies or in galaxies currently undergoing enhanced star formation. Two kinds of models are thus possible and have been advanced by Bouwens & Silk (1996) to maintain such a population over a wide range of redshifts. In the first one, new blue galaxies are continually formed and leave red fading remnants whereas in the second one, star formation occurs recurrently. We adopt the last scenario and will discuss in the conclusion the reasons for this choice. For the sake of simplicity, we assume that all vBG form stars periodically. In each period, a burst phase with a constant star formation rate (SFR) τ_b and the same initial mass function as in FRV is followed by a quiescent phase without star formation. A good agreement with observational constraints is obtained with 100 Myr long burst phases occurring every Gyr.

3.2 Luminosity function

Because bursting galaxies rapidly redden and fade during inter-burst phases, we may not assign a single LF by absolute magnitude, independently on color. We therefore prefer to adopt for vBG a Schechter function determined by τ_b .

The lack of vBG at $z \gtrsim 0.4$ in Cowie et al. (1996) redshift distribution is particularly constraining for the LF. It may be interpreted in two ways. Either vBG formed only at low redshifts ($z < 0.3$) or the lack is due to the exponential cut-off in the Schechter LF. Physical arguments for such low formation redshifts are weak. Scenarios invoking a large population of blue dwarf galaxies, as proposed by Babul & Rees (1992), generally predict a higher redshift of formation ($z \sim 1$). Adopting the last solution, we get $M_{b_j}^* \sim -17$ ($H_0 = 100 \text{ km.s}^{-1}.\text{Mpc}^{-1}$) for galaxies with $B - I < 1.6$ and may constrain the other parameters of the LF. As noticed by Bouwens & Silk (1996), a steep LF extending to very faint magnitudes leads to a large local ($z < 0.1$) excess in the

Galaxy type	$M_{b_j}^*/\tau_b^*$	α	ϕ^*
E	-20.02	-1.	$1.91 \cdot 10^{-3}$
S0	-20.02	-1.	$1.91 \cdot 10^{-3}$
Sa	-19.62	-1.	$2.18 \cdot 10^{-3}$
Sb	-19.62	-1.	$2.18 \cdot 10^{-3}$
Sbc	-19.62	-1.	$2.18 \cdot 10^{-3}$
Sc	-18.86	-1.	$4.82 \cdot 10^{-3}$
Sdm	-18.86	-1.	$9.65 \cdot 10^{-3}$
vBG	$3.95 \cdot 10^5$	-1.3	$6.63 \cdot 10^{-2}$

Table 1. Luminosity functions parameters ($H_0 = 100 \text{ km.s}^{-1}.\text{Mpc}^{-1}$). For vBG, we give the SFR during the burst phase τ_b^* at the LF knee in $M_\odot.\text{Myr}^{-1}$.

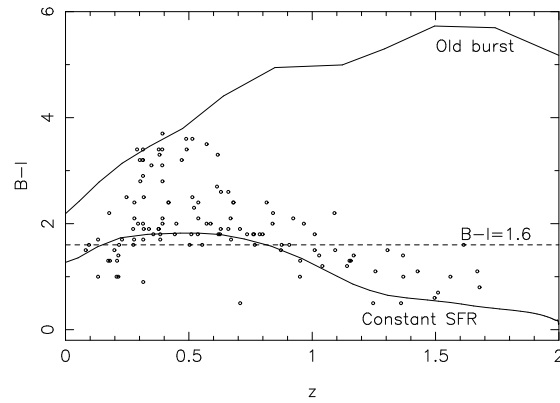


Figure 1. $B - I$ versus z for galaxies from Cowie et al. (1996) sample. The thick lines define the envelope of normal galaxies. The upper one holds for a 13 Gyr old initial burst without subsequent star formation and the lower one for a 10 Gyr old galaxy forming stars at a constant rate. The dashed line separates galaxies at $B - I = 1.6$. A significant fraction of galaxies are observed outside the envelope at $z \sim 0.2$, with $B - I < 1.6$.

redshift distribution. A steep slope ($\alpha < -1.8$) is however only necessary to reconcile predicted number counts with observations in a flat universe. In an open Universe, a shallower slope is possible. In the following, we adopt $\alpha = -1.3$ for vBG. The normalization is taken in agreement with UV counts and the Cowie et al. (1996) redshift distribution.

4 GALAXY COUNTS

Galaxy counts and the amplitude of the projected correlation function by color in an open Universe ($\Omega_0 = 0.1$, $\lambda_0 = 0$, $H_0 = 65 \text{ km.s}^{-1}.\text{Mpc}^{-1}$), obtained with our modelling of vBG and the standard scenarios[†] discussed in FRV, are presented in Fig. 2 to 6. For ‘normal’ types, we use the $z = 0$ SSWML LF of Heyl et al. (1997), after deduction of the contribution of vBG. Characteristics of the LF finally adopted are given in table 1. Though faint in the blue, vBG play an essential role in UV bright counts thanks to their

[†] A constant SFR and $z_{\text{for}} = 2$ are assumed for Sd-Im galaxies.

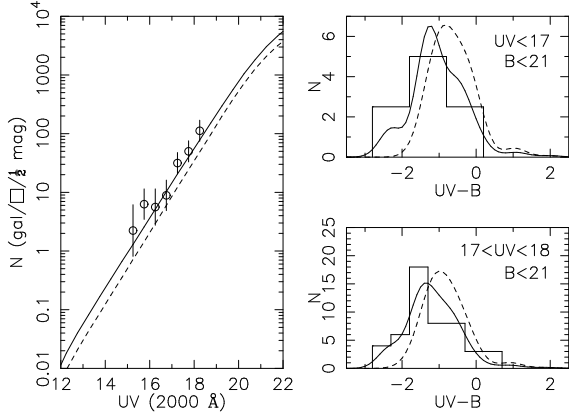


Figure 2. Number counts and color distributions predicted with Marzke et al. (1994) LF (dashed) and with vBG (see text) and observed Heyl et al. (1997) LFs (solid) compared to the observations of Armand & Milliard (1994) (circles and histograms). Color distributions are normalized to the areas of the histograms.

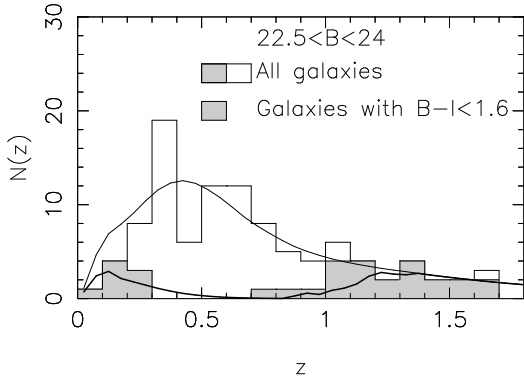


Figure 3. Predicted redshift distribution ($22.5 < B < 24$) compared to the observations of Cowie et al. (1996). The thick line is for galaxies with $B - I < 1.6$ and the thin line for all galaxies.

blue $UV - B$ colors and give a much better agreement on Fig. 2, both in number counts and color distributions.

Their contributions to counts at longer wavelengths is however much smaller. They represent less than 10 per cent of the total number of galaxies at $B = 22.5 - 24$ in Cowie et al. (1996) redshift survey and may thus not be the main explanation of the excess of faint blue galaxies observed over the model without evolution. High redshift, intrinsically bright galaxies forming stars at a higher rate in the past are the main reason as it clearly arises from the $z > 1$ tail of normally blue galaxies. In an open Universe, these galaxies reproduce the faint B and even U counts, assuming a normalization of the LF fitting the bright counts of Gardner (1996) as discussed in FRV. The agreement with the Hubble Deep Field (HDF, Williams et al. 1996) in the blue is notably satisfying. Though a small deficit may be observed in the $F300W$ band (3000 Å), the $F300W - F450W$ (3000Å–4500Å) color distribution is well reproduced (Fig. 5). The

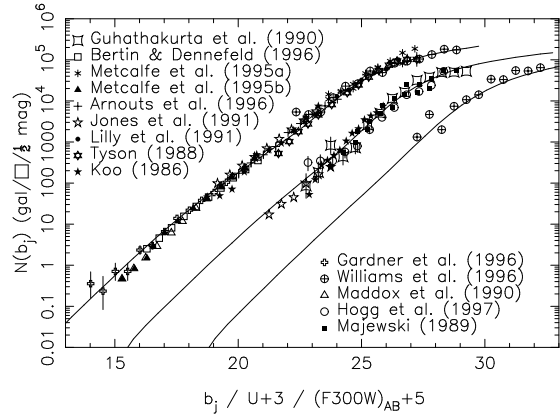


Figure 4. Number counts in b_j (left), U (middle) and $F300W$ (right).

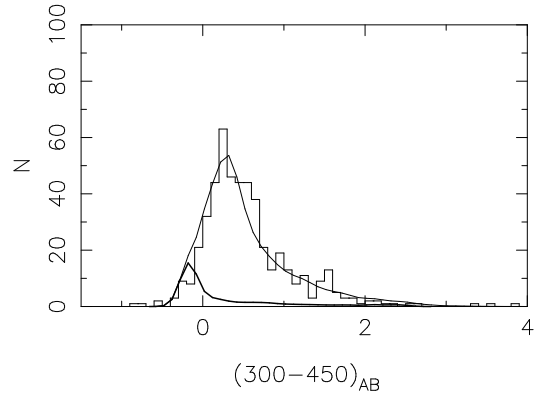


Figure 5. $F300W - F450W$ color distribution in the HDF for $(F300W)_{AB} < 27.75$ and $(F450W)_{AB} < 28.75$ at 80 per cent completeness. Thin line: all galaxies. Thick line: vBG only.

fraction of vBG at these faint magnitudes is still small; they are therefore not the main reason for the agreement with HDF data.

From this previous analysis, it is clear that vBG are difficult to constrain in the visible from broad statistics like number counts and even color distributions. The angular correlation function might be promising since it is more directly related to the redshift distribution. In a $B_J = 20 - 23.5$ sample, Landy, Szalay & Koo (1996) recently obtained an unexpected increase of the amplitude A_w of the angular correlation function with galaxy colors $U - R_F < -0.5$, and suggested that this might be due to a population of vBG located at $z < 0.4$. We compute A_w from our redshift distributions, assuming the classical power law for the local spatial correlation function and no evolution of the intrinsic clustering in proper coordinates. A slope $\gamma = 1.8$ and a single correlation length $r_0 = 5.4h^{-1}$ Mpc (see Peebles (1993)) are adopted for all types. The increase of A_w in the blue naturally arises from our computations (Fig. 6) and is due to vBG. The interval of magnitude, the faint M^* and the

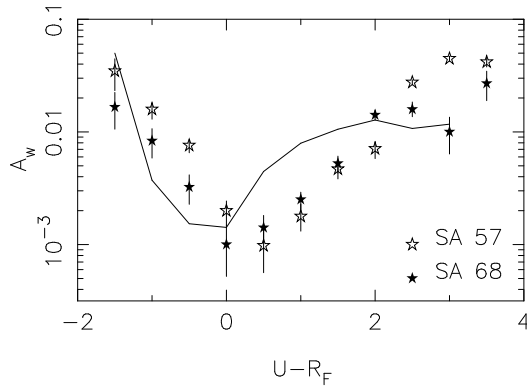


Figure 6. Amplitude at 1° of the angular correlation function in $B_J = 20 - 23.5$ as a function of $U - R_F$ color in bins of 1 magnitude wide. Stars are from Landy et al. (1996). The solid line is the amplitude predicted without evolution of the intrinsic clustering in proper coordinates.

color criterion conspire to select galaxies in a small range of redshift. In spite of the simplicity of our computation of A_w , the trend we obtain is very satisfying. Modelling improved by extra physics or type effects might better fit the A_w -color relation, but at the price of an increased number of parameters.

5 CONCLUSION

We modelled the vBG appearing notably in UV counts with cycling star formation. Our modelling agrees well with the constraints brought by the 2000\AA bright counts (Armand & Milliard 1994), the redshift survey of Cowie et al. (1996) and the angular correlation function of Landy et al. (1996). The cycling star formation provides very blue colors in a more physical way than by assuming a population of unevolving galaxies. The continual formation of new bursting galaxies might lead to similar predictions in the UV-optical, but would produce a high number of very faint red remnants. Future deep near-infrared surveys should provide discriminations between these scenarios. The hypothesis of cycling star forming galaxies has however some theoretical support. The feedback of supernovae on the interstellar medium, may lead to oscillations of the SFR (Wiklind 1987; Firmani & Tutukov 1993; Li & Ikeuchi 1988). Since the probability of propagation of star formation increases with galaxy mass (Coziol 1996), according to the stochastic self propagation star formation theory (Gerola, Seiden & Schulman 1980), this behaviour should be more frequent in small galaxies. More regular SFR might be attained in more massive ones. The nature of vBG is poorly constrained, but we tentatively identify them from their typical luminosity and $H\alpha$ equivalent width ($\sim 200\text{\AA}$) with HII galaxies (Coziol 1996).

Very blue galaxies, as modelled in this paper, are only a small fraction of the number of galaxies predicted at faint magnitudes in the visible and are not the main reason for the excess of blue galaxies, although they may cause some confusion in the interpretation of the faint surveys. In an open

Universe, the population of normal high redshift star forming galaxies, even with a nearly flat LF, reproduces fairly well the counts till the faintest magnitudes observed by the Hubble Space Telescope. As is now well established, this population is however, unable to explain the excess of faint blue galaxies in a flat Universe. Increasing strongly the number of vBG (for example, with a steeper slope of the LF) may not be the solution since it would lead to an excess of galaxies at very low redshift which is not observed. This result depends however on the hypotheses of pure luminosity evolution and null cosmological constant. A flat Universe might still be possible if other evolutionary scenarios are favoured by new observations in the far-infrared and submillimeter.

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